THE HORNS REV WIND FARM AND THE OPERATIONAL EXPERIENCE WITH THE WIND FARM MAIN CONTROLLER

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ABSTRACT

This paper describes the Horns Rev Offshore Wind Farm and operational experiences with the Wind Farm Main Controller. The wind farm was built in 2002 by the Danish utility group Elsam, and has now been in regular operation for a long period. The wind farm was the first to be equipped with advanced centralised control of both active and reactive power. With the Wind Farm Main Controller it is possible to operate the wind farm as a wind power plant. The paper starts with an introduction to the general features of the wind farm and main controller, and then describes the daily operational experience with the advanced control modes.

KEY WORDS

Wind farm controller, power control, grid integration, primary and secondary control, operational experience

I. INTRODUCTION

The Horns Rev offshore wind farm is the first wind farm built as part of the Danish Government's offshore wind energy programme. It was built by the Danish utility group Elsam in 2002 and consists of 80 Vestas V80/2MW wind turbines. The wind farm is situated on a natural reef called Horns Rev in the North Sea 14 to 20 km from the shore at the westernmost point of Denmark.

Figure 1. The Horns Rev Wind Farm seen from the air. The wind farm covers more than 20 km^2

In the electrical supply system, control is implemented as primary and secondary control, where the primary control acts on fast frequency deviations with the purpose of keeping equilibrium between the instantaneous power consumption and production for the area in question. For secondary control - or balance control - the area is divided into a number of control zones, and the aim is to balance the production with the demand within the different zones and to keep up the agreed exchange of power with other zones. This control form is enacted by manually issuing production schedules to the power-producing units in each zone. Uncontrolled production units such as large wind farms will disturb both the instantaneous equilibrium and the balance in the grid.

With the Horns Rev wind farm, a number of new concepts for overall control of active and reactive power have been introduced. These new concepts place stringent demands on the remote control system. Within the envelope area between the wind farm power curve and the available wind speed, the wind farm is able to participate in both primary and secondary control. A Wind Farm Main Controller (WFMC) is installed to handle both types of control. The WFMC is designed and developed by Elsam Engineering A/S.

The WFMC includes several different control schemes to increase the flexibility of power production from the wind farm. These are introduced to ease and improve the daily operation of the grid seen from the point of view of Elsam's central control centre. The controller receives setpoints for active and reactive power from the central control centre and afterwards distributes corresponding setpoints to the individual turbines.

The paper will deal with the use of the different control forms of the WFMC.

The overall conclusion is that the advanced control functions are almost indispensable for maintaining the balance in the grid, irrespective of whether this is done by a large producer responsible for balancing his own production or by the responsible system operator for other producers.

II. THE HORNS REV OFFSHORE WIND FARM

The wind farm at Horns Rev is located approximately 15 km into the North Sea off the westernmost point of Denmark. The location is shown in figure 2.

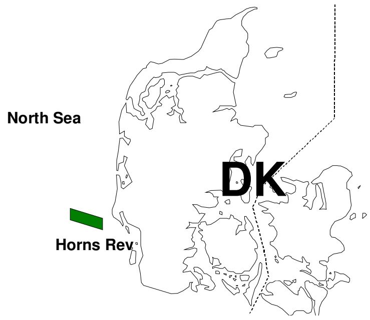

Figure 2. The Horns Rev offshore wind farm situated between 14 and 20 km into the North Sea

The installed power is 160 MW from 80 wind turbines in an almost square pattern. The turbines are arranged along 10 lines each with eight turbines. Pairs of lines form 32 MW clusters. Each cluster is connected to the offshore transformer substation where the 33/150 kV transformer is located. The principle is illustrated in figure 3.

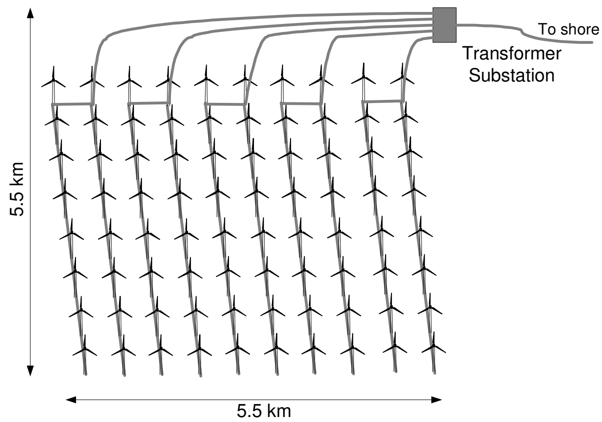

Figure 3. Connection of the turbines to the offshore transformer substation

From the substation, a submarine cable leads to the shore where it is terminated in an existing substation.

All power cables have integrated optic fibers for the remote control system.

The turbines at Horns Rev

Vestas Scandinavian Wind Technology A/S tendered successfully for the supply of the turbines. The selected type is the Vestas V80 2 MW offshore turbine with OptiSpeed technology. The hub height is 70 metres and the rotor has a diameter of 80 metres, which gives a maximum tip height of 110 metres above mean sea level. Some of the turbines are shown in figure 4.

The turbines are all equipped with a helihoist platform at the rear end of the nacelle. For service visits, personnel access the turbine via this platform from a helicopter. The turbines can also be accessed by boat.

Figure 4. Vestas V80 2 MW offshore turbines at Horns Rev

The transformer substation at Horns Rev

The transformer substation module is situated off shore and near the wind farm. The module holds a helicopter deck, a step-up transformer, 150 kV, 34 kV and communication systems as well as the low-voltage distribution system, all containerised. There are also facilities for service personnel and a back-up diesel generator.

Figure 5. Transformer substation module

III. WIND FARM MAIN CONTROLLER

To make the wind farm able to participate in both primary and secondary control, a WFMC is installed. The controller is designed and developed by Elsam Engineering A/S in collaboration with grid specialists from Elsam and Eltra. The purpose of the WFMC is to make the wind farm act as a single production unit instead of 80 individual generators.

The controller includes a number of control possibilities to enable Elsam to use the wind farm as a wind power plant in a similar way as Elsam uses the conventional power plants to keep the power equilibrium as agreed on the Nordic electric power market.

Power control

The wind farm is able to participate in the control tasks as conventional power plants, constrained only by the limitations imposed at any time by the existing wind conditions.

During periods with reduced transmission capacity in the grid (eg due to service or replacement of components in the main grid) the wind farm is able to operate at reduced power levels with all turbines running. This is called the *Absolute Production Limiter*.

Another aspect is that the wind farm is able to participate in the regional secondary control. This is called *Balance Control*.

Passing weather fronts and thunderstorms can cause large and fast variations in the power production. Obviously, decreasing wind speeds cannot be avoided, but when the wind speed increases, the wind farm is able to impose a positive rate of change (dP/dt) limitation. This is called *Power Rate Limitation*.

In some periods it may be advantageous to run the wind farm as a spinning reserve. To make this work properly the wind farm is controlled so the power production is an adjustable number of MWs below the possible power. This is called *Delta Control*.

The principle of all the mentioned control functions is illustrated in figure 6.

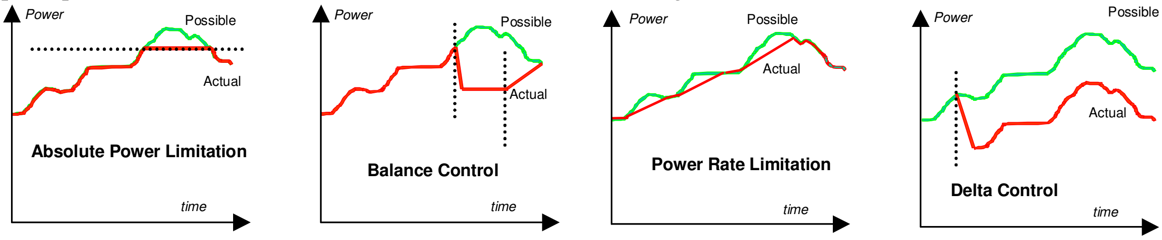

Figure 6. Outline of the active power control functions. The plots show the possible power and the actual achieved power with the different control functions active

Frequency control

The frequency control (primary control) affects the whole UCTE grid and is carried out on a proportional basis by the UCTE participants. The wind farm is able to participate in the frequency control.

The implemented frequency control follows the characteristic shown in figure 7.

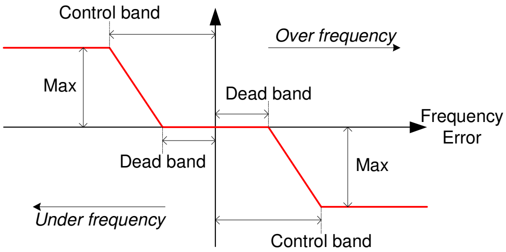

Figure 7. Characteristic of frequency control

All settings are adjustable, i.e. dead band, control band gain, and max/min.

Voltage and reactive power control

The specifications in [1] mention the operating range of the voltage at the land-based 150 kV substation during normal operation. In some periods the area is subjected to severe salt storms and the grid is operated at voltages as low as 130-140 kV, where the normal operating voltage is 165-169 kV. The transformer on the platform has an automatic on-load tap changer with an adjustment range of 129-177 kV.

The basic requirement to reactive power compensation is that the wind farm is reactive power neutral at the 34 kV terminals of the offshore transformer. Because the turbines can both produce and absorb significant amounts of reactive power, the wind farm is able to perform voltage control on the 150 kV side of the transformer or keep a constant production or absorption on the 34 kV side.

Communication

The illustration in figure 8 shows how the WFMC communicates with the surroundings. The SCADA system is VestasOnline Professional. Parameters in the WFMC are set directly from VestasOnline. The WFMC communicates with each turbine and also a measuring front end. All communication to and from the WFMC is handled through an OPC interface via an Ethernet TCP/IP-based network.

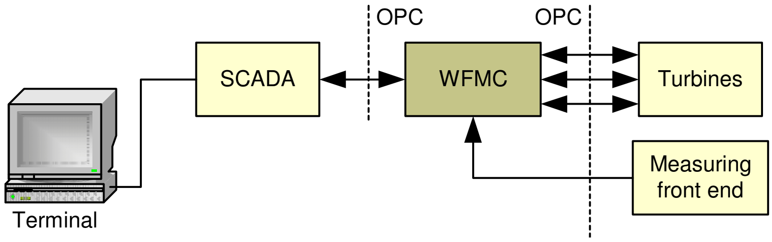

Figure 8. Communication principle in the WFMC – the communication interface is OPC

The communication parts of the WFMC are developed in collaboration with Vestas.

Based on data from the individual turbines and measured, summed data from the transformer station, the WFMC distributes control signals back to the turbines.

Within the wind speed found at any time, the wind farm is controlled as a single unit by means of the control functions mentioned above.

An essential parameter in the control structure is to know the power capability both in the individual turbines and in the wind farm as a whole. Each turbine determines its own active and reactive power capability from an estimated "free wind speed" in front of the turbine. The estimation of the free wind speed is based on knowledge of the actual pitch angle, power and rotor speed.

IV. Operational Experience

With the Horns Rev Offshore Wind Farm, it is now possible to investigate the dynamic performance of large-scale wind farms under various weather conditions. This brings out unique knowledge that can be used in the design and in the estimation of production from future large-scale offshore wind farms.

In several situations, large power fluctuations have been observed. The fluctuations usually appear on days when large rain showers or thunderstorms pass the wind farm. Two of these situations are shown in figure 9 and figure 10.

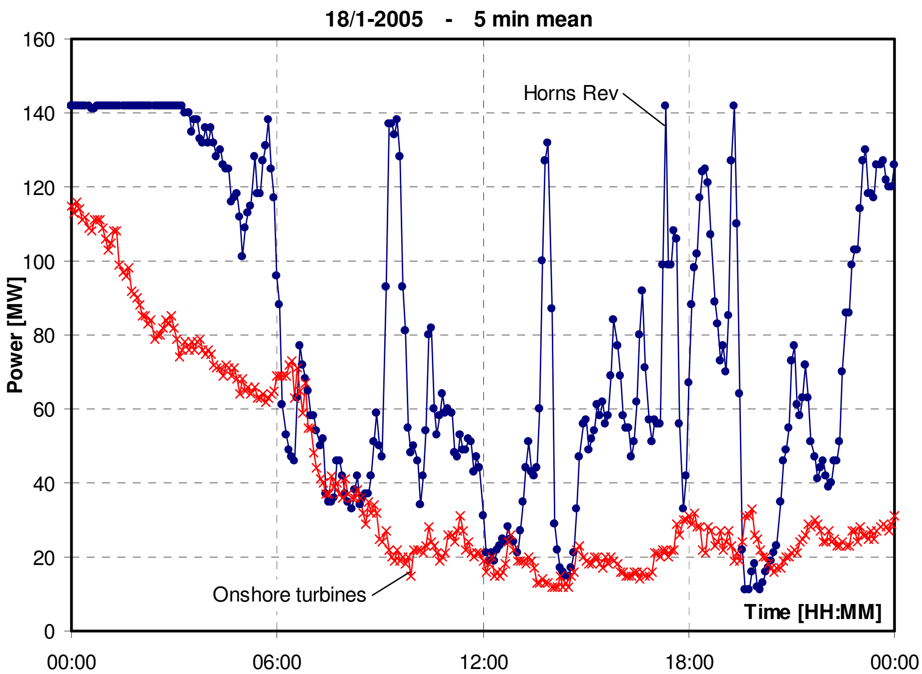

Figure 9. Power fluctuations during a day with many rain showers

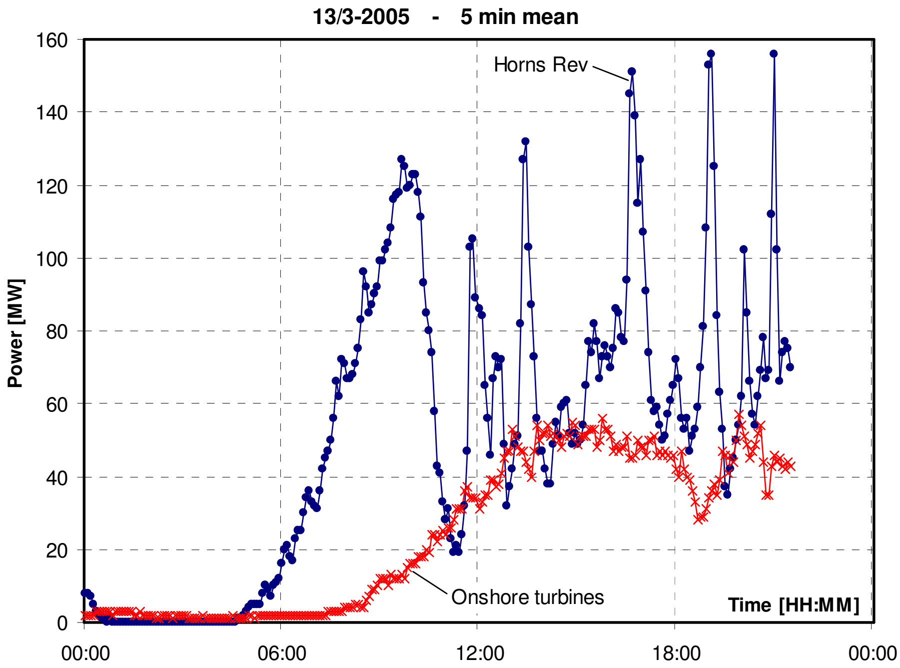

Figure 10. Power fluctuations during a day with many rain showers

The first plot is from 18 January 2005, and the second is from 13 March 2005. Every dot in the plot represents a 5-minute mean value. The upper curve is the production at Horns Rev, while the lower curve is the production from a number of turbines placed on shore all over Jutland and Funen. Compared to the production from the onshore turbines in the same period, the production from Horns Rev is quite fluctuating. The conclusion is that placing a lot of wind turbines in a fairly small area may, in some cases, result in large power fluctuations due to local weather situations. To some extent, these fluctuations can be handled with the WFMC by using the *Power Rate Limiter*.

On 20 January 2005, the wind speed increased to a level just above 25 m/s almost instantly across the whole wind farm. A measurement of this event is shown in figure 11.

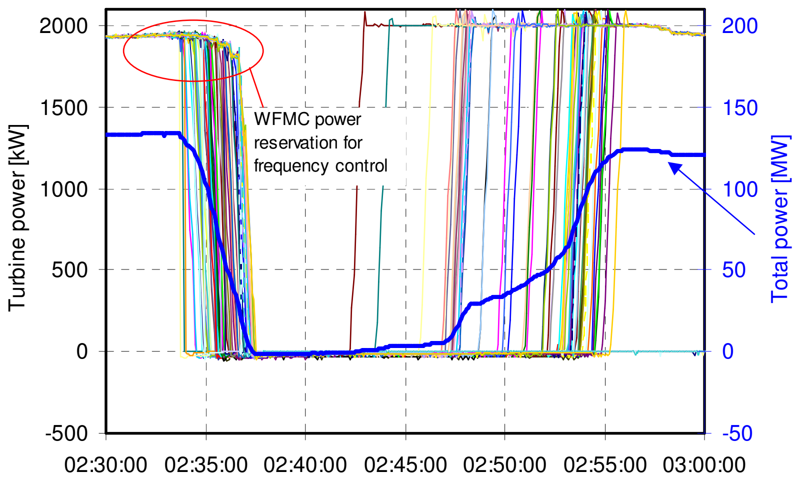

Figure 11. Shutdown of the turbines because the wind speed exceeds 25m/s. The plot shows the production from the individual turbines as well as the total power from the whole wind farm.

This caused all turbines to shut down within a few minutes due to high wind speed. Then a few minutes later, the wind speed fell below 25 m/s again, and the turbines started up again, one by one. This caused the whole wind farm to go from full power to no production within three minutes. Then there was almost no production for about 10 minutes and after 7-8 minutes the full production returned. During that night, similar events occurred several times.

Please note that the total power during full load is not 160 MW. This is due to the fact that some of the nacelles were brought ashore for maintenance and upgrades at the time of the measurement.

On a "normal" day of operation, several of the control functions in the WFMC are sometimes active simultaneously. A situation in which this happened is shown in figure 12.

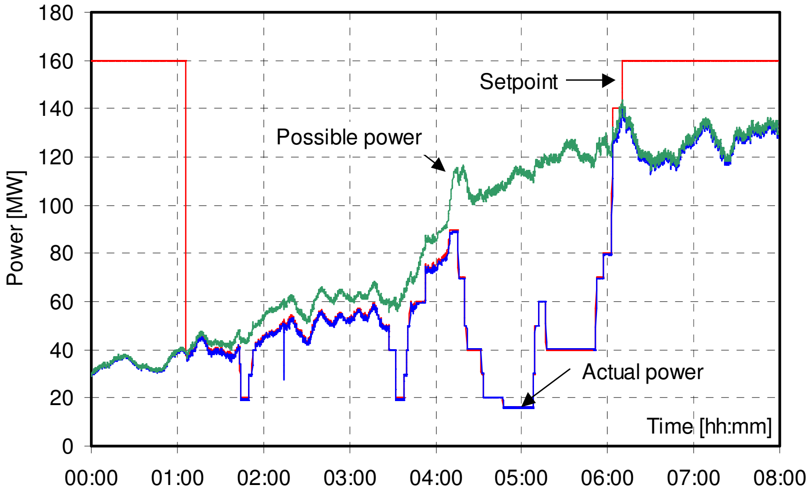

Figure 12. Balance control and reservation for frequency control at the same time

At about 01:10, the frequency control is activated with a spinning reserve that can be used in case of underfrequency. At about 01:40, a manual balance order is issued. After a few minutes a new order is sent, and shortly after that the balance control is cancelled again. The frequency control still keeps some MWs in reserve for the next hours. The dip of power at about 02:10 is actually caused by the frequency control reducing the power because a fast frequency rise occurred at that time. At about 03:30, a new set of balance orders is issued. Please note the time at about 03:45-04:00 when balance orders increase the power close to the possible power. Even though the balance control requests increased production, the frequency control does not allow it. The frequency control has a higher priority than the balance control in the WFMC. This means that when the WFMC needs extra MWs for spinning reserve it will obtain this because it overrides all other functions. From about 04:00 and two hours ahead the power is reduced significantly because of overproduction in the grid. Then the balance control and frequency control are cancelled, and the wind farm returns to normal operation.

Two more events in which the WFMC is used are shown in figures 13 and 14.

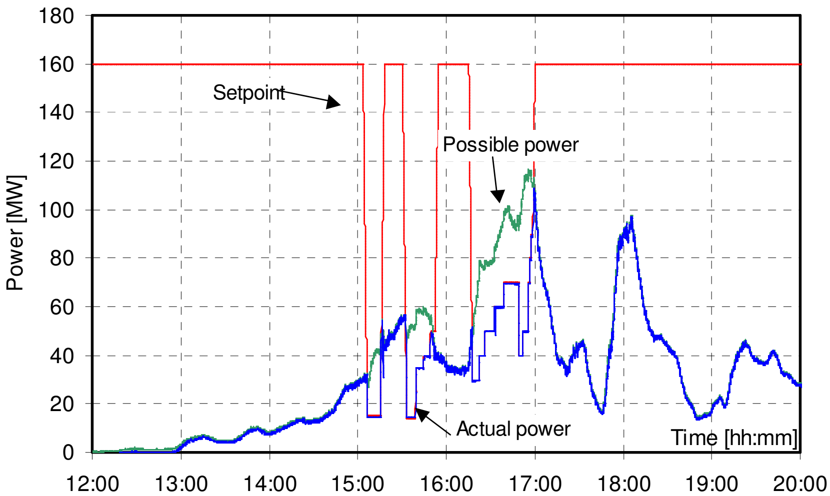

Figure 13. Balance control

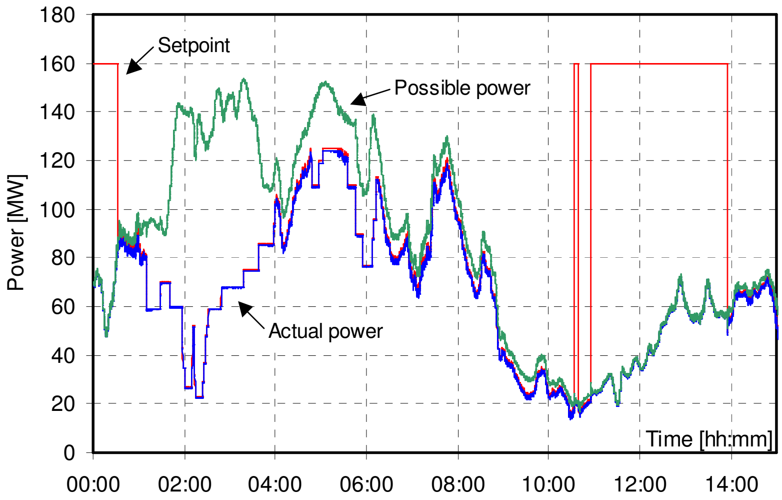

Figure 14. Balance control and reservation for frequency control at the same time

All the situations mentioned above illustrate that the advanced control functions in the WFMC are almost indispensable for maintaining balance in the grid, irrespective of whether this is done by a large producer responsible for balancing his own production or by the responsible system operator for other producers.

V. Conclusion

To manage requirements to power control, a Wind Farm Main Controller (WFMC) has been developed. It communicates with the turbines and the remote control system via an Ethernet TCP/IP-based network. The WFMC is designed and developed by Elsam Engineering A/S and makes the wind farm able to act as a wind power plant. With the WFMC the wind farm is able to handle both primary and secondary control on the same level as conventional power plants.

The controller includes a number of control possibilities to enable Elsam to use the wind farm as a wind power plant in a similar way as Elsam uses the conventional power plants to keep the power equilibrium as agreed on the Nordic electric power market.

The advanced control functions in the WFMC are almost indispensable for maintaining balance in the grid, irrespective of whether this is done by a large producer responsible for balancing his own production or by the responsible system operator for other producers.

VI. References

[1] Eltra, "Specifications for Connecting Wind Farms to the Transmission Network", second edition, ELT1999-411a, www.eltra.dk/media/1030_12321.pdf.

VII. Author Biography

Jesper Runge Kristoffersen earned his Master degree in electrical engineering in 1996 from Aalborg University, Institute of Electrical Engineering in Denmark. In the period 1996-1999 he was with Danfoss Drives A/S in Denmark as a research engineer. Since 1999 he has been with Elsam Engineering A/S in Denmark as a control engineer dedicated to the design and analysis of advanced control strategies, simulation, and control of power systems. His main field of activity is now within wind turbines and wind farms. He has been the key figure in the design, development and implementation of the Wind Farm Main Controller for the Horns Rev Offshore Wind Farm.